

# Sustainability evaluation of Concentrated Solar Power (CSP) projects under Clean Development Mechanism (CDM) by using Multi Criteria Decision Method (MCDM)

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## ABSTRACT

Climate change has caused growing concern in the international community. The Kyoto Protocol was signed by a majority of the world with the clear intention of reducing emissions. Clean Development Mechanism (CDM) is a part of the Kyoto Protocol and allows industrialized countries to reduce their emission by making contribution to developing countries. In this study, several research papers related to sustainability and multi-criteria analysis of energy projects were reviewed and classified based on their focus, motivation and contribution to achieve a comprehensive summary. Additionally, this paper presents a review of multi criteria decision methods and sustainability indicators under five pillars: technical, economic, social, environmental, and risk. Moreover, sustainability analysis of worldwide CDM concentrated solar power (CSP) projects was performed by using MAUT method. The analysis was repeated based on several scenarios including different criteria and criteria weights. The purpose of this research is proposing a framework and providing an understanding for decision makers to evaluate the sustainability of CDM energy projects. This work can provide perceptions to future installations and further insights for the development of sustainable CDM energy projects around the world.

## 1. Introduction: fighting with climate change and looking for a sustainable future

Climate change is a result of human activities and threatens the planet irreversibly. These activities must be controlled and eventually replaced by cleaner or renewable technologies. Industrialized and developing countries have been working on solutions for climate change. Thus, some countries have agreed to sign agreements to share responsibility for the consequences of these human activities. *Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change, which commits its Parties by setting internationally binding emission reduction targets* [1]. The Clean Development Mechanism (CDM) was developed at the third Conference of Parties (COP3) of the United Nations Framework Convention on Climate Change (UNFCCC) in 1997 [2]. CDM allows developed countries to commit an emission limitation and to construct an emission-reduction project for developing countries. Thus, wealth and technology will be transferred to developing countries to reach sustainable development goals. In order to reach Kyoto Protocol target, both clean fossil technologies and renewable energy projects are supported by CDM.

CDM projects can be found in developing countries worldwide. The

first project started in Brazil in 2005, and it was registered during the first commitment period from 2008 to 2012. During these years, 5193 CDM projects were registered with certified emission reductions (CERs) of 1.115.241,36 ktons of CO<sub>2</sub>e. Asia including a great contribution of China and India is the continent with the highest percentage of CDM projects (83%) and this represents 86% of the world's total issued CERs. Moreover, Latin America is the second continent, which has a good potential to develop more projects, especially in Brazil and Mexico. On the other hand, in Africa and Middle East, there are limited projects which are just 2% of the total CDM projects around the world.

CDM projects are mainly focused on renewable energy and methane reduction projects. Also, renewable energy projects can be categorized as: electricity generation (72%), energy efficiency (14%), fuel switching (3%), and methane reduction projects (1%). Moreover, between renewable energy, wind (72.651,36 MW) and hydro power (54.554,99 MW) generation projects had significant shares in the first commitment period: 2008–2012 [3].

Sustainability assessment of CDM projects is crucial for developed and industrialized countries to understand project's contribution to emission reduction and sustainable development. These assessments can be divided into four groups: guidelines, checklists, negotiated

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targets and multi criteria methods. Guidelines are directives, which describe sustainable development features in a project. Checklists include specified questions which must be answered to evaluate the project in qualitative way. Negotiated targets are defined objectives of project by participants to measure the sustainability [2]. Lastly, MCDM is a well-known decision technic to compare the alternatives based on determined sustainability criteria. The focus of our paper is also sustainability analysis with MCDMs.

In order to evaluate the sustainability of CDM projects, SD-TOOL01, Sustainable Development Co-Benefits tool, was developed. This tool assesses the sustainability in a qualitative manner by asking check-list questions related to three main areas: environmental, social and economic. Moreover, it is voluntary to be prepared by project participants and coordinating/managing entities [4]. Although it was a useful instrument, this qualitative and voluntary evaluation tool was not sufficient for sustainability assessment. In order to understand the projects' impacts on climate change and to compare alternatives for next projects, a quantitative multi criteria approach must be considered by decision makers.

This research presents a comprehensive review of sustainability and multi criteria decision analysis of energy projects. It has three main contributions. The first one is to provide a framework for decision makers to evaluate the sustainability of CDM projects. The second contribution is to identify sustainability assessment criteria and methods for CDM energy project. The third one is to establish sustainability analysis of worldwide solar thermal CDM projects by using MCDM to check the proposed approach. Also, the analysis was repeated based on several scenarios including different criteria and their weights to understand the importance of criteria choice. Finally, the overall objective of this paper is proposing a structure to evaluate the sustainability of CDM energy projects. This work can provide further perceptions for the development of sustainable CDM energy projects around the world.

The paper is organized as follows: Section 2 includes literature review of sustainability and multi criteria analysis of energy project. Section 3 describes summary of sustainability evaluation indicators. In Section 4, multi criteria decision methodologies utilized for energy projects were discussed. In Sections 5 and 6, sustainability evaluation of solar thermal CDM projects has performed as a case study and its results and discussions are given, respectively. Finally, Section 7 concludes the paper.

## 2. Literature review: sustainability and multi-criteria analysis of energy projects

The main purposes of CDM projects are to implement an emission-reduction project by industrialized countries and making contribution to sustainable development (SD) of developing countries. Although SD has many definitions according to different sources, Brundtland Report in 1987 defines it as: "SD is development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Generally, SD of projects are evaluated by using three important indicators which are called *the magic triangle*: environmental, social, and economic [5]. In some cases, technology and risk are also considered as additional criteria as shown in Fig. 1.

Sustainable development indicators can be chosen at different levels depending on the scope of the project: global, national, and project level [6]. Global and national levels can be categorized as macro level assessments which evaluate big scale goals of the projects. Additionally, depending on the assessment, evaluation criteria show changes as illustrated in Table 1.

Furthermore, project level assessment allows host countries to analyze sustainability of specific projects. When a different level of SD assessment is considered, the role players and objectives change accordingly. The actors can be central and regional governments, related ministries, municipalities or project developers. Also the objectives of

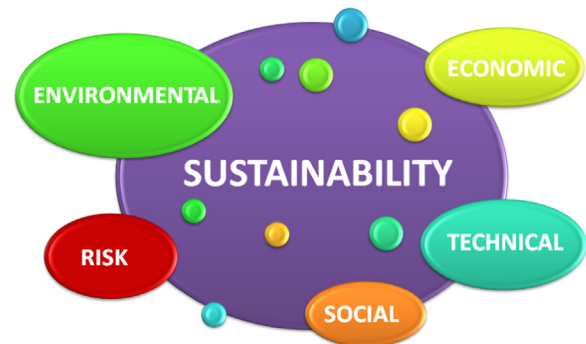


Fig. 1. Sustainability evaluation criteria.

Table 1

Examples of sustainable development criteria at different levels [6].

Dimension	Global	National	Local (Project)
<b>Economic</b>	GDP	Trade	Employment
<b>Environmental</b>	GDP/Capita	Taxes	
	GHG emissions	Biodiversity	Local air quality
	Biodiversity	Air quality	Local water quality
<b>Social</b>		Water quality	
	HDI	Employment	Health
		Poverty reduction	Community participation
			Capacity building

assessment can vary based on project's purposes: reducing emissions, increasing employment in the region, increasing capacity, transferring technology, and starting a new industry.

In order to propose a framework for sustainability evaluation of CDM projects, detailed literature review has performed and summarized in this section. Sustainability assessment and multi criteria analyses in energy subject are studied in the literature for different purposes. The articles can be categorized in six main groups according to their objectives as follows:

- 1) Technology/source/component comparison [7–24]
- 2) Energy project comparison/selection [2,5,6,25–32]
- 3) Energy/electricity mix options assessment [33–38]
- 4) Site selection for energy projects [39–43]
- 5) Evaluation of hybrid energy systems [44–47]
- 6) Assessment of source potential [48,49]

In the first category, technology/source/component comparison papers exist and they were summarized in Table 2. Generally, technology or energy source evaluation studies were found in the literature [7–18,20,21]. Decision makers can assess several renewable energy options, different energy technologies, solar energy alternatives based on defined sustainability criteria. These studies are crucial to decide best option or to understand the most sustainable one between alternatives. Additionally, in this category, studies including particular component comparison for solar energy can be found. Examples of this category are choosing best solar thermal collection technology for electricity generation [19], design of a solar thermal collector [22], optimization of a solar-dish Brayton system [23], and maximization thermal efficiency and power of Stirling heat engine [24]. These papers demonstrate that multi-criteria decision can be applied not only to evaluate technology/source, but also to compare components of specific technology. These evaluation approaches are also applicable to CDM projects when individual technologies or energy sources are assessed.

In the second categorization, studies with project comparison/selection were discussed as listed in Table 3. These papers make essential

**Table 2**  
Technology/source/component comparison.

Objective of The Study:	MCDM	Case Study	Main contribution of the study:	Ref.
Assess the contribution of five low-emission energy technologies to sustainable development	Delphi	Poland	Study includes the comparison of wind on-shore, wind off-shore, biomass/biogas, photovoltaic and nuclear technologies. Photovoltaic technology has the first ranking between alternatives.	[7]
Decision of bioenergy production technologies	Fuzzy set theory	Iran	Globally existing bioenergy technologies are ranked. It is distinguished that production of biogas, heat and electricity from, agricultural, municipal and industrial wastes achieve higher overall performance.	[8]
Compare the selected sugarcane-based bio refineries centered systems	PROMETHEE	Brazil	Comparison of Four sugarcane bio refineries for bioethanol, sugar, animal feed and electricity production which were designed based on sugar mill and ethanol distilleries.	[9]
Evaluating renewable power generation technologies	AHP	Saudi Arabia	Solar PV, solar thermal, wind, waste to energy and geothermal alternatives were evaluated. Solar photovoltaic followed by concentrated solar power was found as the most favorable technology.	[10]
Electricity technology options' comparison	Weighted sum method (WSM)	USA	Solar PV, CSP, Wind, Bio power, NGCC, Coal, Hydro, Geothermal, Nuclear were assessed based on sustainability criteria. Bio power and geothermal (flash and binary) had the highest sustainability.	[11]
Comparison of solar thermal power technologies	Delphi method	–	Parabolic trough, power tower, parabolic dish, linear Fresnel technologies were evaluated and weighted with a large group of experts' participation.	[12]
National-scale sustainable assessments of renewable energy technologies	PROMETHEE	Scotland	Onshore wind, Offshore wind, Hydro power, Wave, Tidal, Geothermal, Photovoltaic, Solar thermal, dedicated biomass, Energy-from-waste, Heat pumps were chosen as alternatives and assessed based on nine sustainability indicators. PV was obtained as the most sustainable technology	[13]
Evaluation renewable energy alternatives	TOPSIS	Greece	Assessment of wind parks, small hydroelectric projects, biomass use for electricity production, biomass exploitation in thermal applications, centralized photovoltaic power systems for electricity production, grid connected photovoltaic systems (roof-top) in buildings, solar collectors in the domestic sector, and solar thermal systems used in the industrial sector. Solar collectors in the household sector had the best sustainability contribution for Greece.	[14]
Comparison of different power plants options	AHP	–	Coal/Lignite, oil, NG, NGCC, nuclear, hydro, wind, PV, biomass, geothermal were selected as alternatives and evaluated. Hydro, geothermal and wind had the highest sustainability.	[15]
Decisions about energy backup and cooling options for parabolic trough concentrated solar power	Weighted Sum Method (WSM)	–	Parabolic trough technology with several thermal storage and wet/dry cooling options were compared under five hypothetical preference scenarios.	[16]
Evaluation of concentrated solar thermal technologies	PROMETHEE	–	Decision between different heat transfer fluids and thermal storage for CSP systems. In the research, seven storage medias are used as alternatives. The best results were obtained for the technologies using molten salts as HTP and for heat storage with two tanks or thermocline considering the maximum salt temperature as around 500°.	[17]
Assessing thermal-energy storage in concentrated solar power (CSP) systems	Fuzzy TOPSIS	–	Several types of CSP systems with different capacity were compared. Solar hybrid systems H1 and H2 had the best ranking in this study.	[18]
Choosing best solar thermal collection technology for electricity generation	AHP	India	Ten alternatives of solar thermal power generation collectors: Parabolic Trough (with synthetic oil or direct steam generation), heliostat (with molten salt, water/steam, volumetric), linear fresnel (GLFR, LFR), parabolic dish (glass), compound parabolic (CPC, linear fresnel lens) were evaluated for different regions. The preferred technology is Linear Fresnel lens with a secondary compound parabolic collector, or the parabolic dish reflector.	[19]
Sustainability analysis of electro dialysis powered by photovoltaic for freshwater production	–	Spain	Freshwater production technologies Reverse osmosis and electro dialysis powered by PV systems are compared based on sustainability indicators.	[20]
Sustainability assessment of biogas production	–	Kenya	Three types of biogas production technologies (Floating-drum, fixed dome, tubular type) were compared. The tubular digester biogas production seems to be more sustainable.	[21]
Decision of design of a novel solar thermal collector using a multi-criteria	AHP	–	Three novel solar thermal collector concepts (Circular, parabolic and elevation) derived from the linear Fresnel reflector (LFR) were developed and evaluated through a multi-criteria decision-making methodology. Between the alternatives, the Elevation Linear Fresnel Reflector (ELFR) has the highest ranking.	[22]
Maximization thermal efficiency and power of Stirling heat engine	TOPSIS	–	Stirling machines with different design parameters (temperatures, power and efficiency) were assessed with MCDM to increase their performance.	[24]

**Table 3**  
Energy project comparison/selection.

Objective of The Study:	MCDM	Case Study	Main contribution of the study:	Ref.
Sustainable evaluation of CDM Projects	Modified MAUT	South Africa, India, Uruguay	The sustainability indicators' choice and the weighting were studied depending on different host countries and the CDM project category. A modified MCDM was proposed.	[2]
Sustainable development contribution of clean development mechanism projects	–	–	A new approach was proposed for sustainability assessment based on text analysis of the project design documents. CDM Project types and categories were listed to understand the contribution of each type of projects to SD.	[5]
Applying Sustainable Development Criteria to CDM Projects	–	–	Prototype Carbon Fund (PCF) projects' sustainability analysis and the evaluation of sustainable development indicators at different levels were discussed.	[6]
Different co-generation scenario analysis	ASPID	Croatia	Three distinctive scenarios including co-generation sector future developments were assessed. The scenario with higher development of cogeneration had the best sustainability ranking.	[25]
Selection of solar-thermal power plant investment projects	AHP, ANP	Spain	Determine a suitable solar-thermal power plant project between twenty-five projects. Three level decisions making has been performed. In each level, criteria were changed to filter the projects, thus the numbers of projects were reduced. This is one the few articles proposing a staged methodology for SD assessment.	[26]
The selection among various renewable energy investment projects	PROMETHEE	Greece	Four different scenarios concerning the exploitation of a geothermal resource were studied to make an investment decision. Also different actors' opinions were taken into account.	[27]
Solar Thermal Electricity (STE) project sustainability assessment	–	Mexico	Assessing the sustainability of a single investment project in order to see the impact of each indicator: economic, social and environmental. Employment creation has a significant effect on Mexican economy while deploying STE projects.	[28]
Establishing a sustainability assessment framework for geothermal projects	The Delphi technique	Iceland	A new approach was proposed to evaluate sustainability analysis for geothermal projects. Suitable indicators were selected with experts' participation.	[29]
Sustainability assessment of solar projects	Modified MCDM	Chile	All solar energy projects (153) in Chile until June 2014 were summarized according to their status and location. The sustainability analysis for 7 PV and 3 CSP projects was performed.	[30]
Geothermal energy project sustainability assessment for different regions	–	Iceland, New Zealand and Kenya	Study showed the sustainability approach for different countries in terms of choosing indicators in geothermal projects.	[31]
Energy projects performance evaluation	AHP and Vikor	Turkey	Energy projects alternatives are wind, hydropower, biogas, natural gas power plants with different capacity and in particular regions. Based on selected criteria, wind power project was chosen as the best option.	[32]

**Table 4**  
Energy/electricity mix options assessment.

Objective of The Study:	MCDM	Case Study	Main contribution of the study:	Ref.
Energy mix options assessment	AHP	Jordan	The Multi-Criteria techniques were used to compare nine electricity generation options, including energy efficiency. Conventional fuels remain fundamental and oil shale, nuclear, biomass and wind energy had the best diversification potential.	[33]
Analysis different RE percentage in energy planning	PROMETHEE I, II	Greece	Scenarios containing different wind, PV and biomass percentage were assessed to see their sustainability. The rankings of alternatives were calculated based on actors' opinion and criteria.	[34]
Assessment of scenarios including different share of energy mix	Not defined	USA	Two different energy mixes including coal, gas, nuclear, hydro, and renewables were defined and evaluated.	[35]
Electricity expansion planning decision	Not defined	Russia	By considering different contribution of nuclear, gas and hydro, electricity expansion planning was developed and several scenarios were analyzed.	[36]
Environmental impacts of electric utility in electrical system planning	MAUT	Canada	The impact of individual electric utility on environment was evaluated.	[37]
Analysis of the evolution of UK energy sector	SMART	UK	Five different options of energy mix including coal, oil, gas, nuclear, hydro and renewables were compared. The rankings were obtained for each criterion.	[38]

contribution to the assessment an energy project before investment decision. In the literature, mainly, selection of renewable energy projects was found. Choice of solar power plant projects [26,28,30], and geothermal energy project sustainability assessment [29,31] are examples in this category. Moreover, evaluation of energy investment projects with different capacity and region, and investment decision of energy projects including different geothermal resources, and cogeneration projects' analysis were discussed in [27,32,25], respectively. Furthermore, there are few studies about sustainability evaluation of CDM projects [2,5,6], which is also focused in the Sections 5 and 6 of our study. In [5], a qualitative approach was proposed for sustainability based on project design document. The types of CDM projects were listed to understand the contribution of each type of projects to sustainable development. Also, in [2,6], indicator selection for sustainability analysis was mentioned.

Besides technology, source or project comparison/selection papers, sustainability or/and MCDM analyses were performed for energy/electricity planning. In Table 4, related examples worldwide were summarized. For the energy planning category, several scenarios for future energy plans for countries were developed. Thereafter, these scenarios were analyzed with MCDM to assess energy mix options [33,35], to see the impact of renewables in energy system planning [34], to analyze the contribution of particular scenarios on electricity expansion planning [36,38], and to investigate the environmental evaluation of energy systems [37]. These studies are important to understand how to evaluate several scenarios with different energy options. Additionally, sustainability criteria utilized in these papers motivate future studies.

As a fourth category, multi criteria analyses were studied in the literature for the purposes of site/location selection for energy projects. A new project can improve local economy, health, education, job opportunities in the region. Also, when CDM projects are established in developing countries, project region or site decision is fundamental to

make better contribution to sustainable development. Thus, related papers summarized in Table 5 can be taken as examples of identifying best or potential location for solar power plants [39–43]. As a result, not only source potential, but also social, economic and environmental aspects of projects should be taken into account to make decisions on location.

Besides comparison of several projects, literature also evaluates hybrid energy systems. In this category, CSP technologies hybridized with power plants using conventional and unconventional fuels, sustainability of hybrid systems including renewables and conventional plants, and revitalization of an existing energy plant are example studies [44–47] listed in Table 6. These revival or hybridization studies are examples for CDM when projects are implemented to improve the performance of existing power plants.

Evaluation of source potential [48,49] studies, the last classification, were mentioned in the literature. In Table 7, Egypt and West Africa papers were summarized based on their objectives and main contribution. The source potential assessment is a significant step of energy project decision. In terms of CDM projects, it is important to evaluate the potential of resource since the capacity increase or project expansion can be done in the further phases of multi staged-projects.

As a conclusion, sustainability and multi-criteria studies in energy subject can be divided into six fundamental categories based on their purposes: technology/source/component comparison, energy project comparison/selection, energy/electricity mix options assessment, site selection for energy projects, evaluation of hybrid energy systems, and assessment of source potential. This classification helps decision makers to apply sustainability assessment to different types of CDM projects. By considering previous studies, sustainability evaluation frameworks can be formed for further analyses of CDM projects.

**Table 5**  
Site selection for energy projects.

Objective of The Study:	MCDM	Case Study	Main contribution of the study:	Ref.
Solar thermal power plant site selection based	Linguistic Choquet integral	China	Three potential locations were assessed to select optimal site for Solar thermal power plant.	[39]
Selection of solar–wind hybrid power station location	AHP	China	Five particular solar–wind hybrid power station site selections were compared by applying MCDM.	[40]
Prioritizing suitable areas for solar technologies	AHP	Tanzania	GIS and MCDM were combined to identify the best location for installing a solar power plant.	[41]
Assessment of regions priority for implementation of solar projects	SWARA, WASPAS	Iran	Study includes identification and prioritization of suitable regions for construction of solar power plants Not only solar potential but also other assets have an importance to decide on solar project location.	[42]
Environmental impact analysis of identifying locations for solar power plants	AHP approach	Spain	Identifying preferable locations for solar power plants based on GIS based MCDM	[43]

**Table 6**  
Evaluation of hybrid energy systems.

Objective of the study:	MCDM	Case study	Main contribution of the study:	Ref.
Thermal power unit with different hybridization comparison	ASPID	Bosnia and Herzegovina	Hybridization of 110 MW thermal power plants was compared considering a coal-fueled boiler, combined cycle gas turbine, hydropower, PV, wind turbines, and biomass power plants.	[44]
Evaluation of hybrid energy systems	Not defined	–	In the study, sustainability of hybrid systems including solar photo-voltaic, wind turbine, biomass, combined cycle gas, and cogeneration systems were analyzed to produce electricity, water, heat and hydrogen.	[45]
Concentrated solar power hybrid plants selection	AHP	–	Distinguishing the most appropriate concentrated solar power (CSP) technologies to hybridize with power plants using conventional and unconventional fuels. Depending on the objective of hybridization, specific technologies had the highest ranking.	[46]
Sustainability analysis of revitalization decision of the thermal power plant	ASPID	Serbia	Revitalization decision of thermal power plant by hybridization with fossil and renewable energy options.	[47]

**Table 7**  
Evaluation of source potential.

Objective of The Study:	MCDM	Case Study	Main contribution of the study:	Ref.
Evaluate offshore wind potential	AHP	Egypt	Three locations with high potential were identified with around 33 GW capacity by using GIS + MCDM.	[48]
Geographical and technical potentials for solar electricity generation	AHP	West Africa	GIS-based estimation of the geographical and technical potentials for solar electricity generation in rural areas.	[49]

### 3. Literature review: indicators for sustainability evaluation

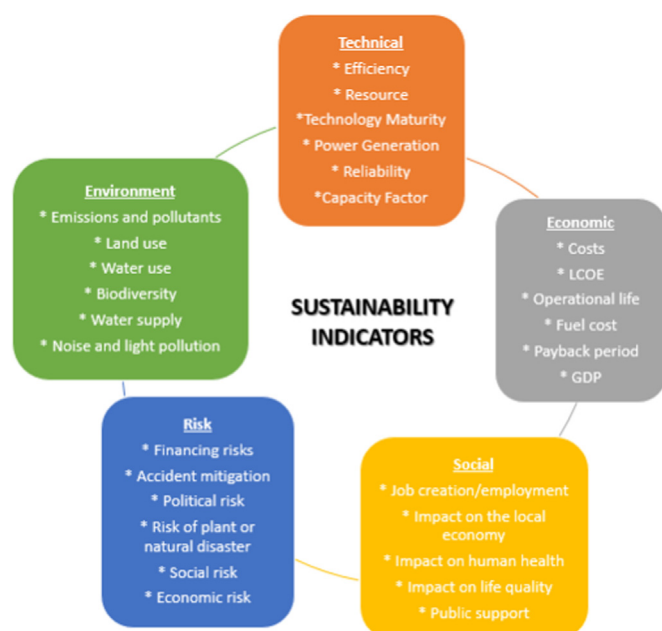
In this section, literature review of sustainability indicators was discussed. Five most commonly used criteria: technical, economic, social, environmental, and risk were mentioned depending on project categorization. In addition to main pillars, frequently utilized sub-indicators were listed in Fig. 2. In the following sections, main indicators are explained.

#### 3.1. Technical

In this section, frequently used technical indicators were explained. Based on the literature, the most commonly utilized technical criteria are efficiency, resource, technology maturity, potential generation, reliability, and capacity factor. Efficiency is percentage or a coefficient showing the ratio of the output energy to the input energy [2,10,12,15,19,22,23,29–31,33,44,45,50–53]. Resource is a criterion to assess source potential or availability [10,29,35,39–44,47,52,53]. Technology maturity shows the recognition of a certain technology and its use in worldwide [8,10,12,13,17,18,34,46,50–53]. Power generation is another widely used indicator which means produced energy/electricity or thermal power in MW, MWh, and MWth [8,13,18,23,35,36,52]. Reliability means the capability of a technology to achieve a required utility [10,12,13,19,21,22,50–53]. Capacity factor is the ratio of its actual output over a period of time, to its potential output [11,15–17,20,30,33,52]. Moreover, other technical criteria can be seen in Table 8 based on the objective of the studies. Finally, technical indicators generally appear in technology/source/component comparison, energy project selection and energy/electricity mix options assessment. When a specific technology is thought in a CDM project, technical indicators of sustainability should be included in the analysis.

#### 3.2. Economic

Another essential sustainability indicator is economic criteria. In the revision of literature, it was obtained that costs, LCOE, operational life, fuel cost, payback period, and GDP were the most commonly mentioned criteria under economic assessment. In terms of economy, costs mean investment, operation and maintenance, or external costs of projects as mention in [9,10,12,14,15,17–22,25,26,30,32–36,38,40,42,44,45,47,50–53]. LCOE is another measure in economic sustainability assessment and reflects the minimum price of the energy which allows the project to recover its costs [11,13,16–18,28,33,38,46,52]. Operational life shows the lifetime of technology or project [10,12,31,35,50–53]. Fuel cost is another important economic indicator, mentioned in [10,12,15,25,36,50,51,53]. Payback period is a measure to understand the feasibility of investment in decision making [21,33,40,42,50–52]. GDP is also an important criterion to measure a country's economy, which is the monetary value of all the finished goods and services produced within a country's borders in a specific time period [5–7,29,49]. Besides criteria mentioned above, other essential indicators such as net present value, fuel saving, unemployment rate, return on investment, R&D expenditure were listed in Table 9. In conclusion, cost effectiveness of a project is always required in all categorization of energy studies. Thus, economic sub-criteria for CDM energy projects should be chosen carefully.



**Fig. 2.** Frequently utilized sustainability indicators.

**Table 8**  
The most commonly utilized technical criteria.

	Technical Indicators	Reference
Technology/source/ component comparison	– Efficiency	– [10,12,15,19,22,23]
	– Resource	– [10]
	– Technology maturity	– [8,10,12,13,17,18]
	– Potential power generation	– [8,13,18,23]
	– Reliability	– [10,12,13,19,21,22]
	– Capacity factor	– [11,15–17,20]
	– Safety of energy system	– [6,10,12,18]
	– Reserve/Production ratio	– [15,21]
	– Demand	– [21]
	– Technology advancement potential	– [12]
	– Exergy efficiency	– [21]
	– Deployment time	– [10,12]
	– Expert human resource	– [10,12]
	– Electricity supply availability	– [10,15]
	– Ease of decentralization	– [10]
	– Safety in covering peak demand	– [12]
	– Scalability	– [12]
	– Level of complexity	– [12]
	– Technical compability	– [12]
	– Network stability	– [12]
	– Continuity and predictability of performance	– [12]
	– Storage hours	– [17]
	– Hybridization	– [18]
	– Micro grid suitability	– [19]
	– Augmentation capability	– [29]
	– Operation temperature	– [29]
	– Logistical feasibility	– [30]
	– Operation temperature	– [29,31]
	– Freezing point of HTF	– [2,6]
	– Availability	– [29]
Energy project comparison/ selection	– Efficiency	– [29–31]
	– Resource	– [29]
	– Capacity factor	– [30]
	– Reserve/Production ratio	– [29,31]
	– Technology advancement potential	– [2,6]
	– Transmission Loss	– [29]
	– Distribution loss	– [31]
	– Duration of plant power outages	– [31]
Energy/electricity mix options assessment	– Efficiency	– [33]
	– Resource	– [35]
	– Technology maturity	– [34]
	– Potential power generation	– [35,36]
	– Capacity factor	– [33]
	– Safety of energy system	– [35]
	– Ease of decentralization	– [38]
	– Safety in covering peak demand	– [38]
Site selection for energy projects	– Dispatchability	– [33]
	– Resource	– [40–43]
	– Demand	– [41,42]
	– Grid connected distance	– [39,40,42,43]
Evaluation of hybrid energy systems	– Accessibility	– [41]
	– Efficiency	– [44,45]
	– Resource	– [44,47]
	– Technology maturity	– [46]
	– Level of complexity	– [46]
	– Integration simplicity	– [46]

**Table 8 (continued)**

	Technical Indicators	Reference
Mentioned in other sources	– Efficiency	– [50–53]
	– Resource	– [52,53]
	– Technology maturity	– [50–53]
	– Potential power generation	– [52]
	– Reliability	– [50–53]
	– Capacity factor	– [52]
	– Safety of energy system	– [50,51]
	– Reserve/Production ratio	– [53]
	– Demand	– [52,53]
	– Technology advancement potential	– [54]
	– Exergy efficiency	– [50,51]
	– Primary energy ratio	– [52]
	– Technical compability	– [52,53]
	– Operational flexibility	– [52]
	– Direct energy consumption	– [52]

### 3.3. Social

As shown in Table 10, the most commonly used social indicators were listed. In order to measure sustainable development contribution of a particular project, social pillar of sustainability must be considered. Examples of social sub-criteria are job creation and employment [2,5,6,8–12,14,20,27–29,31–33,38,44,47,50–54], impact on the local economy [5,6,12–14,29,34,39,54], impact on human health [5,6,10,25,28,52], impact on life quality and society [8,32,47,54], and public support [13,39,51,53]. Depending on project's purposes, more criteria can be chosen to assess social impact of project. Social pillar also has an importance for CDM projects which has an objective of bringing wealth and new technologies to developing countries.

#### 3.3.1. Sociopolitical

Besides social indicators, it can be found sociopolitical pillar. In some studies, sociopolitical concerns of projects were evaluated into social parts or separately. In Table 11, some important socioeconomic criteria were listed. Social and political acceptance is the most commonly used indicator to assess projects [10,12,25,33,34,42,50,52]. National energy security/energy independency has an importance for developing countries due to utilize national resources or technologies [10,14,29,31]. Additionally, compatibility with the national energy policy and benefits [10,12], maintain leading position as energy supplier [10] can be found in the literature to evaluate sustainability of projects.

### 3.4. Environment

The main objective of CDM projects is developing emission reduction projects. Thus, in order to assess the sustainability of a chosen project, determination of environmental criteria is an essential step. Environmental pillar of sustainability was mentioned in many studies such as technology/source/component comparison, energy project selection, energy/electricity mix options assessment, site selection, evaluation of hybrid energy systems. Emissions/pollutants, land use, water use, biodiversity and ecological impact, water supply, noise pollution and light pollution are often found in the literature as illustrated in Table 12. Emissions/pollutants can be thought as CO<sub>2</sub>, CO<sub>x</sub>, SO<sub>x</sub>, NO<sub>x</sub> and other potential pollutants depending on assessment [6–14,16,20,21,23,25,28–40,44,45,47,50–54]. Land use is also fundamental due to land cost, respect of life in the region and natural reserves, which was mentioned in following studies: [2,7,8,10–13,18,19,22,29,33,35,39,42,46,50–53]. Water use [8,9,11,12,16,19,22,28,29,33,35,40,46] and water supply

**Table 9**  
The most commonly used economic criteria.

	Economic Indicators	References
Technology/source/ component comparison	– Costs	– [9,10,12,14,15,17–22]
	– LCOE	– [11,13,16–18]
	– Operational life	– [10,12]
	– Fuel cost	– [10,12,15]
	– Payback period	– [21]
	– GDP	– [7]
	– Trade balance	– [7]
	– Competitiveness of economy	– [7]
	– Fuel saving	– [21]
	– Unemployment rate	– [7]
	– Market maturity	– [10,12]
	– National economic development	– [10]
	– Site advantage	– [10]
	– Availability of funds	– [12]
	– Economic feasibility	– [8]
	– Offsetting	– [9]
	– Infrastructure cost	– [9]
	– Economic sustainability	– [7]
	– Cross-subsidization	– [7]
	– Sensitivity to price volatility	– [7]
	– Energy security	– [7]
	– Balanced development of regions	– [7]
Energy project comparison/ selection	– Costs	– [25,26,30,32]
	– LCOE	– [28]
	– Operational life	– [31]
	– Fuel cost	– [25]
	– GDP	– [5,6,29]
	– Return on investment	– [27,31]
	– Fuel saving	– [27]
	– R&D expenditure	– [29,31]
	– Unemployment rate	– [29]
	– Regional economy improvement	– [2]
	– Business continuity	– [32]
	– Financial Performance	– [32]
	– Product Performance	– [32]
Energy/electricity mix options assessment	– Costs	– [33–36,38]
	– LCOE	– [33,38]
	– Operational life	– [35]
	– Fuel cost	– [36]
	– Payback period	– [33]
	– Trade balance	– [38]
	– Competitiveness of economy	– [38]
	– Fuel saving	– [34]
Site selection for energy projects	– Costs	– [40,42]
	– Payback period	– [40,42]
	– Net Present Value	– [42]
	– Return on investment	– [40]
	– Net profit on capita	– [40]
Evaluation of hybrid energy systems	– Costs	– [44,45,47]
	– LCOE	– [46]
Assessment of source potential	GDP	[49]
Mentioned in other sources	– Costs	– [50–53]
	– LCOE	– [52]
	– Operational life	– [50–53]
	– Fuel cost	– [50,51,53]
	– Payback period	– [50–52]
	– Net Present Value	– [50–53]
	– Trade balance	– [54]
	– Competitiveness of economy	– [52]
	– National economic development	– [53]
	– Affordability	– [52]

[2,5,6,31,39,41,52] is vital for a region. Therefore, in some areas with lack of water, this indicator must be considered, too. Biodiversity and ecological impact are crucial subjects and each national or local government have different attitude. Hence, for a particular regions which is under protection, this criterion must be considered [5,6,8,10,12,14,28,29,32,39,40,52,53]. Noise pollution and light pollution are important indicators to see the impact of projects on region and it is significant that the projects will not disturb the living people [29,31,40,50–53]. Land transformation is a measure for deterioration and alteration of the land, which should also be evaluated in projects [2,5,16,29,31,52]. Furthermore, air quality in the region, soil quality degradation, acidification potential, need for waste disposal and nuclear waste are extra indicators to assess sustainability depending on projects' objective.

### 3.5. Risk

In the literature, risk pillar is frequently seen for energy project comparison/selection and site selection for energy projects. Financing risks [26,27,29], accident mitigation [31,33], political risk [26,42], risk of plant or natural disaster [26,53], social risk [40], economic risk [42], and environmental risk [42] were frequently utilized criteria for risk assessment in sustainability. In Table 13, other risk groups can be found for different objectives. Evaluation of CDM projects in terms of risk has an importance due to uncertainties in developing countries' conditions. Thus, considering risk pillar can change the assessment results apparently.

## 4. Multi Criteria Decision Methodologies

Energy projects are not identical and it is not easy to make a relative comparison. Also, one dimensional decision-making technic is not sufficient to analyze projects in many aspects. Multi-criteria decision methodology is a well-known and used technique to make a decision based on comparison of alternatives. The main goal is to choose the alternative having the highest results according to the evaluation criteria. With these methods, both quantitative and qualitative criteria can be evaluated by decision makers [55].

MCDM methods have common basic steps for decisions: (1) structure the decision process, alternative selection and criteria formulation, (2) determine criteria weights, (3) construct evaluation matrix, (4) select a suitable method, and (5) calculate final ranking and make decision between alternatives [55,56]. MCDM can be categorized in multiple ways and basically classified into two groups according to problem-solving techniques: multi-objective decision-making (MODM) and multi-attribute decision-making (MADM). MODM is used to optimize conflicting objectives by programming and there might be no single solution. On the contrary, MADM is utilized to identify the most preferred alternative or to classify them [53,57].

Additionally, methodology classifications due to complexity (such as elementary, unique synthesizing and outranking) [50] or other categorization (such as outranking, utility based, miscellaneous methods) [53] can be found in the literature. The most commonly used methods are analytical hierarchy process (AHP), preference ranking organization method for enrichment evaluation (PROMETHEE), the elimination and choice translating reality (ELECTRE), the technique for order preference by similarity to ideal solutions (TOPSIS) and, multi-attribute utility theory (MAUT) [50,55]. The methods found in the literature are listed in Table 14 where the classifications proposed by various authors are combined and the commonly used methods [50,51,53,55,56,58] are highlighted.

After all, new methods, which are derived from classical methods or the combinations of two methods, can be utilized to make a multi-criteria decision-making in some analyses. It must be considered that there are no better or worse MCDMs; however, some techniques are more appropriate than others to approach to particular energy problems [27].

**Table 10**  
Frequently utilized social criteria.

	Social Indicators	References
Technology/source/component comparison	– Job creation and employment	– [8–12,14,20]
	– Impact on the local economy	– [12–14]
	– Impact on human health	– [10]
	– Impact on life quality	– [8]
	– Public support	– [13]
	– Salary	– [21]
	– Fatalities	– [11]
	– Eliminating social inequality	– [7]
	– Energy security of households	– [7,9]
	– Feasibility	– [10]
	– Social Effects on food security	– [8]
	– Compatibility with political, legislative framework	– [8]
	– Shaping new energy culture	– [7]
	– Job creation and employment	– [2,5,6,27–29,31,32]
	– Impact on the local economy	– [5,6,29]
Energy project comparison/selection	– Impact on human health	– [5,6,25,28]
	– Impact on life quality	– [32]
	– Salary	– [6,28]
	– Fatalities	– [29]
	– Eliminating social inequality	– [2,6]
	– Product stewardship	– [32]
	– Social governance	– [32]
	– Stakeholder participation	– [2]
	– Improved Service Availability	– [2]
	– Capacity development	– [2]
	– Job creation and employment	– [33,38]
	– Impact on the local economy	– [34]
	– Fatalities	– [33]
	– Diversity	– [38]
	– Accountability in different weather conditions	– [35]
Site selection for energy projects	– Impact on the local economy	– [39]
	– Public support	– [39]
	– Local government support	– [39]
	– Effect on Progress of Surrounding Region	– [42]
	– Job creation and employment	– [44,47]
Evaluation of hybrid energy systems	– Impact on life quality	– [47]
	– Salary	– [47]
	– Diversity	– [44]
	– Feasibility	– [46]
	– Job creation and employment	– [50–54]
Mentioned in other sources	– Impact on the local economy	– [54]
	– Impact on human health	– [52]
	– Impact on life quality	– [54]
	– Public support	– [51,53]
	– Fatalities	– [52]
	– Diversity	– [52]
	– Social benefits	– [50,51]

**Table 11**  
The most commonly used sociopolitical criteria.

	Sociopolitical Indicators	References
Technology/source/component comparison	– Social and political acceptance	[10,12]
	– National energy security/energy independency	[10,14]
	– Compatibility with the national energy policy and benefits	[10,12]
	– Maintain leading position as energy supplier	[10]
Energy project comparison/selection	Social and political acceptance	[25]
	National energy security/energy independency	[29,31]
Energy/electricity mix options assessment	Social and political acceptance	[33,34]
Site selection for energy projects	Social and political acceptance	[42]
Mentioned in other sources	Social and political acceptance	[50,52]

#### 4.1. MAUT method

MAUT is one of the most commonly utilized multi-criteria decision methods for energy analysis. In literature, it can be found that it is used for energy policy decision, environmental impact assessment and electric power system expansion planning [36–38]. MAUT takes into account the decision maker's choice in the form of the utility function. This function is described over a set of attributes, in which the utility of each criterion does not have to be linear [55]. The aim of this method is to acquire united measure of the utility of an alternatives' set. The main steps of MAUT can be summarized as follows [2]:

- 1) Structure a hierarchy of evaluation attributes: Attributes are decided to analyze alternatives. Therefore, arranging a hierarchical tree of attributes will make evaluation clear and easy. For example, after choosing the main attributes such as technical, economic and environmental, it must be defined sub attributes such as i) capacity, ii) efficiency, iii) plant load factor for technical and so on.
- 2) Describe utility functions to value projects: In MAUT, the utility functions  $u(c_i)$  varies between 0 and 1 and depends on the goal, e.g. maximizing production, efficiency, job creation etc. or minimizing

**Table 12**  
The most commonly used environmental criteria.

	Environmental Indicators	References
<b>Technology/source/ component comparison</b>	– Emissions, pollutants	– [7–14,16,20,21,23]
	– Land use	– [7,8,10–13,18,19,22]
	– Water use	– [8,9,11,12,16,19,22]
	– Biodiversity and ecological impact	– [8,10,12,14]
	– Land transformation	– [16]
	– Environmental management	– [10,12]
	– Soil quality degradation	– [8]
	– Resource efficiency	– [7]
	– Risk of failure/accident	– [7,18]
	– The impact of local residential life	– [13]
	– Need for waste disposal	– [10]
	– Fossil fuel depletion	– [9]
	– Freshwater eutrophication	– [9]
	– Use of chemicals	– [17]
	– Environmental impact	– [7]
	– Interference in the landscape	
<b>Energy project comparison/ selection</b>	– Emissions, pollutants	– [6,25,28–32]
	– Land use	– [2,29]
	– Water use	– [28,29]
	– Biodiversity and ecological impact	– [5,6,28,29,32]
	– Water supply	– [2,5,6,31]
	– Noise and light pollution	– [29,31]
	– Land transformation	– [2,5,29,31]
	– Environmental management	– [2,5,29,31]
	– Air quality in the region	– [6,29]
	– Soil quality degradation	– [29,31,32]
	– Resource efficiency	– [29,31]
	– The impact of local economy and tourism	– [31]
	– The impact of local residential life	– [28,29]
	– Acidification potential	– [2]
	– Fossil fuel depletion	
<b>Energy/electricity mix options assessment</b>	– Emissions, pollutants	– [33–38]
	– Land use	– [33,35]
	– Water use	– [33,35]
	– Safety of supply	– [34,38]
	– Nuclear waste	– [38]
<b>Site selection for energy projects</b>	– Emissions, pollutants	– [39,40]
	– Land use	– [39,42]
	– Water use	– [40]
	– Biodiversity and ecological impact	– [39,40]
	– Water supply	– [40,41]
	– Noise and light pollution	– [40]
	– Soil quality degradation	– [40]
	– The impact of local economy and tourism	– [40]
	– The impact of local residential life	– [39,40]
	– Energy saving benefits	– [39]
	– Transportation condition	
<b>Evaluation of hybrid energy systems</b>	– Emissions, pollutants	– [44,45,47]
	– Land use	– [46]
	– Water use	– [46]
	– Safety of supply	– [47]
	– Risk of failure/accident	– [47]

**Table 12 (continued)**

	Environmental Indicators	References
<b>Mentioned in other sources</b>	– Emissions, pollutants	– [50–54]
	– Land use	– [50–53]
	– Biodiversity and ecological impact	– [52,53]
	– Water supply	– [52]
	– Noise and light pollution	– [50–53]
	– Land transformation	– [52]
	– Safety of supply	– [52]
	– Air quality in the region	– [54]
	– Risk of failure/accident	– [54]
	– The impact of local economy and tourism	– [52]
	– Energy saving benefits	
	– Acidification potential	
	– Need for waste disposal	

**Table 13**  
Frequently used risk criteria.

	Risk Indicators	References
<b>Energy project comparison/ selection</b>	– Financing risks	– [26,27,29]
	– Accident mitigation	– [31,33]
	– Political risk	– [26]
	– Risk of plant or natural disaster	– [26]
	– Risk of plant or natural disaster	– [26]
	– Country risk	– [26]
	– Change in energy policy	– [26]
	– Water supply risk	– [26]
	– Resource risk	– [26]
	– Proximity to power line	– [26]
	– Land price	– [26]
	– Technology availability risk	
	– Access	
<b>Site selection for energy projects</b>	– Social risk	– [40]
	– Political risk	– [42]
	– Risk of plant or natural disaster	– [42]
	– Economic risk	– [42]
	– Environmental risk	– [42]
<b>Mentioned in other sources</b>	– Time delay risk	
	Risk of plant or natural disaster	[53]

emissions, cost, fuel usage etc. For maximization and minimization criteria, the utility functions are calculated as follows respectively:

$$uj(\max) = \frac{A_j - A_{\min}}{A_{\max} - A_{\min}} \quad (1)$$

$$uj(\min) = \frac{A_{\max} - A_j}{A_{\max} - A_{\min}} \quad (2)$$

3) Define weights to combine criteria: The weights of criteria are defined to indicate its relative importance. In literature, it can be found objective and subjective weighting methods. Generally, subjective methods are used to make decisions in which expert opinions are engaged. Criteria weights show changes based on case-specific rather than fact. The objective weighting methods utilize the measurement data and information to define the criteria weights. For different purposes, varieties of weighting criteria methods are studied in the literature. Direct weighting and Analytic Hierarchy Process (AHP) which are commonly used technics for weighting. In our research, entropy method and direct weighting were utilized as a weighting method because it is an objective and widely used

**Table 14**  
MCDM categorization.

Elementary Methods	<ul style="list-style-type: none"> <li>Weighted sum method (WSM) [11,16]</li> <li>Weighted product method (WPM)</li> </ul>	
Outranking Methods	<ul style="list-style-type: none"> <li>Preference ranking organization method for enrichment evaluation (PROMETHEE) [9,13,17,27,34,50,51,53,55,56,58]</li> <li>The elimination and choice translating reality (ELECTRE) [50,51,53,55,56,58]</li> </ul>	
Unique synthesizing criteria	<ul style="list-style-type: none"> <li>Multi-attribute utility theory (MAUT) [2,37,50,51,53,55,56,58]</li> <li>Technique for order preference by similarity to ideal solutions (TOPSIS) [14,18,23,24,50,51,53,55,56,58]</li> <li>SMART [38]</li> <li>Grey relational analysis</li> </ul>	<ul style="list-style-type: none"> <li>Data envelopment analysis [52]</li> <li>Multi-attribute value theory (MAVT)</li> <li>Utility theory additive (UTA)</li> <li>Fuzzy weighted sum</li> <li>Fuzzy maximum</li> </ul>
Utility based Methods	<ul style="list-style-type: none"> <li>Analytical hierarchy process (AHP) [10,15,19,22,26,32,33,40,41,43,46,48–51,53,55,56,58,59]</li> <li>Analytic Network Process (ANP) [26]</li> </ul>	
Miscellaneous Methods	<ul style="list-style-type: none"> <li>Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH)</li> <li>Compromise programming (CP)</li> <li>VIKOR [32]</li> <li>Preference assessment by imprecise ratio statements (PAIRS)</li> </ul>	<ul style="list-style-type: none"> <li>Novel approach to imprecise assessment and decision environments (NAIADE)</li> <li>Value trees</li> <li>The Shapley value</li> <li>SWARA &amp; WASPAS [42]</li> <li>ASPID [25,44,47]</li> </ul>

method for energy projects [2,50].

#### 4.1.1. Entropy method definition and application

Entropy method is an objective weighting method which is used when the numerical values of criteria are known. These kinds of methods allow experts to value criteria objectively and to see the relation between criteria apparently. The entropy indicates that how much the criteria demonstrate the information of system and how big the uncertainty of criteria is and it is calculated as given here [50]:

A vector of  $x_j = (x_{1j}, x_{2j}, \dots, x_{mj})$  represents the set  $X$  in terms of the  $i_{th}$  criteria which is described as follows:

$$X_j = \sum_{i=1}^m x_{ij}; j = 1, 2, \dots, n. \quad (3)$$

Then the entropy measure of  $j_{th}$  criteria contrast intensity is:

$$e_j = -\frac{1}{\ln m} \sum_{i=1}^m \frac{d_{ij}}{D_j} \ln \frac{d_{ij}}{D_j} \quad (4)$$

Finally, the normalized weights can be calculated as follows:

$$w_j = \frac{1 - e_j}{\sum_{j=1}^n (1 - e_j)}; \sum_{j=1}^n w_j = 1 \quad (5)$$

- Identify the different project alternatives and their attributes for the decision makers: Project alternative and all attributes of projects must be determined in this level. Attributes of projects can be evaluated in a quantitative or qualitative way.
- Aggregate the results (on the level of alternatives) of the evaluation of each criterion: After converting attributes to the utility functions and defining weights, alternatives are combined in a single value by using this equation:

$$Utility = \sum_{j=1}^n w_j * u_{ij} \quad (6)$$

Thus, the scores of each project are obtained and compared according to each evaluation criteria or final score of each alternative.

### 5. Case study: application of sustainability analysis to solar thermal CDM project by using MAUT method

Between the renewable sources, solar energy is an alternative to have zero emission energy production facility. With the technological developments, the cost has reduced considerably. The total installed solar capacity has reached 232 GW in 2015 around the world with the major contribution of China, Japan, USA and Germany [60]. Due to the huge potential of sun, cleanness and having zero fuel cost, it is expected

that the energy production share of solar power projects under CDM will continue increasing in the future. Between solar technologies, concentrated solar power (CSP) is an important technology. It can produce both thermal energy and electricity. In addition to this, CSP technology provides storage facility which is an important feature to have sustainable and continuous energy production [61].

Within the scope of this study, eleven solar thermal CDM projects were taken into consideration to make a sustainability analysis by using MAUT method. The solar thermal CDM projects were chosen from various host countries include Morocco, India, Israel, United Arab Emirates (UAE), China, Thailand, Chile, and Lebanon. This comprises all solar thermal and concentrated solar CDM projects available up to March 2017. All projects have been assigned a short name to refer its location and scale (ex: Morocco\_160, India\_125, Israel\_120 etc.). The useful information about projects is obtained from their project design document (PDD) which can be accessed from UNFCC web page. If more information is needed, other documents such as environmental analysis, impact documents can be used for the missing data. Moreover, to obtain detailed data, one may contact the project participant directly and evaluation matrix of alternatives can be filled correctly.

In our research, the capacity of projects varies from 2.2 to 160 MW and some of these projects aim to produce electricity when others were designed to produce thermal energy. The most commonly utilized CSP technology is parabolic trough technology with ten projects and there is also one project with linear Fresnel technology. Besides, some projects have an additional fossil fuel consumption to provide electricity or thermal energy in long term. In this section, brief summaries of selected solar thermal projects are listed in Table 15 according to their capacities presented in the CDM.

In this paper, the project sustainability analysis of CSP Projects is developed in terms of four main indicators as presented in Table 16. The three traditional sustainability evaluation criteria (environmental, economic and social) are complemented with technical dimension. Technical criteria include the size of the plant (capacity, MW), its production (electricity to the grid, MWh), and the length of the construction stage (construction period, year). To evaluate economic dimension of projects, investment cost (USD), operation and maintenance cost (O&M cost, USD/year) and power plants total estimated life (service life, years) are decided. Moreover, environmental criteria involve the reduced emission by using solar energy (emission reduction, tCO<sub>2</sub>eq), total area used to construct power plant (land use, hectares), additional fossil fuel usage (fossil fuel usage, %). Finally, as a social indicator the number of potential employment is considered as job creation.

After deciding the indicators for analysis, the values of these indicators were obtained for chosen solar thermal CDM projects. Table 17 illustrates the Sustainability evaluation matrix of selected thermal CDM

**Table 15**  
Summaries of selected solar thermal CDM projects [62].

PROJECT NAME	
Morocco_160:Ouarzazate I Concentrated Solar Power Project	The Ouarzazate I Parabolic Trough Solar Power Project includes the construction of a solar power plant with installed capacity of 160 MW with 3 h of thermal energy storage. The project supplies around 497.5 GWh per year to the Moroccan electricity grid with an average emission reduction of 278,695 tCO <sub>2</sub> per year. The Project contributes to sustainable development by promoting the development of a new green industry in Morocco, creating local jobs during the development, construction and the operation of the power plant, and encouraging training in the renewable field.
India_125:Greenhouse Gas Emission Reductions Through Thermal Solar Power Technology	The project included implementing 125 MW large-scale grid connected Compact Linear Fresnel Reflective (CLFR) power plant project in Jaisalmer, India. With this project including technology transfer activities, 2151,322 t of Carbon Dioxide emissions are reduced during operation of solar power plant. Project is located in rural areas of India. Thus, it makes contribution to society as improvement of basic roads. Also by the help of this project, investors are encouraged to make similar clean projects. Water is utilized as HTF due to the environmental concern.
Israel_120: Shneur Solar Thermal Grid-Connected Power Plant in Ze'elim	It is planned to construct a grid-connected solar thermal power plant with an installed capacity of 120 MW, having a capacity factor of 22.34% and a technical lifetime of 30 years in Israel. Natural gas (NG) is utilized as additional power generation supply when it is required. The power plant supplies approximately 204 GWh of electricity per year to the national grid with an emission reduction of 137,181.5 tCO <sub>2</sub> e per year by replacing electricity generated by the coal-heavy national grid. 30 permanent jobs during operation, as well as over 500 jobs during its construction are provided with this project.
AbuDhabi_100: Abu Dhabi solar thermal power project, Masdar	The purpose of the project was to install grid connected solar thermal power plant with 100MWe capacities in Abu Dhabi, the capital of UAE. Within the scope of the project activity, 624 efficient parabolic trough solar collector assemblies (SCA) were installed. In this project, storage is not taken into account and natural gas is used for auxiliary firing when it is needed. The power plant is approximately expected to produce 286 MWth or 100 MWe gross powers. By concerning environment, dry cooling is considered in this project.
China_50: Inner Mongolia Erdos 50 MWp Groove Type Solar Thermal Project	The project includes parabolic trough type solar thermal power plant providing a total capacity of 50 MW. The proposed project is located in China. The annual electricity production is about 122,630 MWh. The estimated annual emission reductions are 102,060 tCO <sub>2</sub> to make contribution to sustainable development. The project supports local sustainable development with reducing the emission of other pollutants resulting from the power generation industry in China, such as SO <sub>2</sub> , NO <sub>x</sub> and other particulate pollutants, creating local employment. The annual operation time of the proposed project is estimated to be 2737 h.
India_50: Solar Thermal Power Plant by Godawari Green Energy Limited	50 MW large-scale grid connected solar thermal power project is aimed to install in India with the reduction of 1131,600 t of CO <sub>2</sub> emissions. The project includes all social, economic, environmental and technological well-being for the area. The capacity factor of plant is estimated as 29.74%. The gross electricity output is 130,263 MWh/year with 25 years operational life.
India_25: Solar Thermal Power project at Kutch District in Gujarat	Construction of 25 MW concentrated solar thermal technology based power project at Kutch in Gujarat in India is the scope of this CDM project. The produced electricity is connected to the regional electricity grid of India under a power purchase agreement. As a heat transfer fluid, synthetic thermal oil is used and 9 h thermal storage is considered. The project reduces 111,204 tCO <sub>2</sub> e emissions annually.
Thailand_5: Thai Solar Energy Solar Thermal Power Plant Project	The purpose of the project is installation a parabolic trough direct steam generator plant with 5.005 MWe capacity which is 100% clean technology to convert sunlight into electricity without any pollution. The project reduces emissions by an amount of 7376 t of CO <sub>2</sub> e per year. Additionally, at the project it is declared that there is limited noise pollution during energy generation which is acceptable and below the regulation standard.
Chile_4.2: Solutions heating up by the implementation of a solar thermal plant	The project is decided to supply 10.5 MW thermal energy to mine processes to increase the water temperature from around 65–85 °C in Tesoro Mine in the North of Chile which has a great solar potential. The project contributes to sustainable development by producing clean energy, decreasing the country dependency on foreign fossil fuels and being the first solar thermal project in Chile that encouraged solar investors.
India_3: Solar Thermal Power Project by APCL	The project activity is installation of 3 MW grid connected CSP Plant at Nelavagulu Village, India. The parabolic trough technology is used for generation of electricity. During the process of generating power through solar energy, no fossil fuel is used. The expected net generation is 5440 MWh/year with reduction of 4880 t of CO <sub>2</sub> e per year. This project has an importance for India in terms of increasing employment opportunities in the area and enhancing local investment and local economy.
Lebanon_2.2: Thermal Solar Plant Project at Zeenni Trading Agency; Bsarma El Koura	The project takes places in Lebanon and the aim of the project is to construct a single-axis tracking parabolic trough solar thermal power plant to partially displace Heavy Fuel Oil (HFO) in order to improve the air quality in the region. Also the project activities which involve technological and knowledge transfer creates employment opportunities for professional, skilled and unskilled labors.

**Table 16**  
Base case sustainability indicators for MAUT analysis.

Sustainability indicators			
Technical	Economic	Environmental	Social
Capacity	Investment cost	Emission reduction	Job creation
Electricity to the grid	O&M cost	Land use	
Construction period	Service life	Fossil fuel usage	

projects which were obtained from PDD and other internet sources (NREL, CSP world etc.).

Whenever information was not available, project developers were contacted, but responses were limited. Therefore, missing information of evaluation matrix was finally estimated by considering each project specifications and similar references in the literature. Thus, assumptions and calculations of missing values which are illustrated with lettered references (a, b, etc.) in Table 17 were shown in Appendix.

After filling evaluation matrix, key project data is presented graphically in Fig. 3. The red circled values represent calculated values.

**Table 17**  
Sustainability evaluation matrix of selected thermal CDM projects.

Project Name	Morocco_160:	India_125:	Israel_120:	AbuDhabi_100:	China_50:	India_50:	India_25:	Thailand_5:	Chile_4.2:	India_3:	Lebanon_2.2:
<b>Technical Indicators</b>											
Capacity (MW)	160.0	125.0	120.0	100.0	50.0	50.0	25.0	5.0	4.2 <sup>(a)</sup>	3.0	2.2
Electricity (MWh/yr)	497,500	226,789	204,000	210,000 [63]	122,630	118,866	130,000 [64]	8000 [65]	7140 <sup>(b)</sup>	5440	3740 <sup>(b)</sup>
Construction (yr)	2.33 [66]	3.00 <sup>(c)</sup>	3.00 <sup>(c)</sup>	3.00	2.00 <sup>(c)</sup>	2.00 [67]	2.00	1.00 <sup>(c)</sup>	1.00 <sup>(c)</sup>	1.00 <sup>(c)</sup>	0.50
Investment (million USD)	460.0 [66]	282.0	473.0	558.0	135.0	285.0 <sup>(d)</sup>	125.0	28.5 <sup>(d)</sup>	14.0 [68]	17.1 <sup>(d)</sup>	12.5 <sup>(d)</sup>
O&M (million USD)	4.80 <sup>(e)</sup>	2.59	10.40	16.50	2.34	3.30 <sup>(f)</sup>	3.90 <sup>(e)</sup>	0.33 <sup>(f)</sup>	0.28 <sup>(f)</sup>	0.20 <sup>(f)</sup>	0.15 <sup>(f)</sup>
Life (yr)	25	25	30	25	25	25	25	20	20	25	50
<b>Environmental Indicators</b>											
Emission (tCO <sub>2</sub> e)	278,695	215,132	137,182	174,800	102,060	113,160	111,204	7376	6454	4880	1685
Land (hectares)	450 [66]	300 <sup>(g)</sup>	300	250 [63]	150 <sup>(h)</sup>	150 [67]	180 <sup>(i)</sup>	110 [65]	13 <sup>(j)</sup>	10 <sup>(j)</sup>	7 <sup>(j)</sup>
Fossil (%)	0%	0%	2%	32%	0%	0%	0%	0%	0%	0%	86% <sup>(k)</sup>
<b>Social Indicators</b>											
Job (N of People)	850 [66]	1288 <sup>(l)</sup>	530	700 <sup>(l)</sup>	515 <sup>(l)</sup>	515 <sup>(l)</sup>	258 <sup>(l)</sup>	130 [65]	55 <sup>(l)</sup>	45 <sup>(m)</sup>	59

Projects were presented and sorted in decreasing capacity to allow identifying scale relationships. Electricity generation per MW (operation hours) was obtained in the range of 1500–2500 h with exception of two projects. Solar thermal plants with storage are designed with a larger solar field, providing more operational hours. (1)–(2) This can be seen in projects: Morocco\_160 and India\_25 which have 3hrs and 9hrs storage facility, accordingly. (3) Investment cost per MW varies based on project size. Utility scale projects tend to have lower cost than small scale projects. Therefore, as seen in the Fig. 3, some utility size projects show less cost than calculated values for small size projects. (4) Emission reduction values are also related to operation hours and TES. This can be obtained for India\_25 project which has 9 h TES. Land use is usually in the range between 2 and 4 ha/MW for projects without TES. (5) However, land use value for Thailand\_5 is well out of range. This value, probably because calculations have been done by project developers to expand the projects in the future (No confirmation was obtained from project developer).

## 6. Sustainability analysis results and discussion: solar projects sustainability varies widely across projects

In this section, analysis results which include MAUT methodology were illustrated. As mentioned in Tables 16 and 17, eleven CDM projects and ten sustainability indicators were chosen for this analysis. Additionally, in the following sub-sections, the results of different scenarios were explained.

### 6.1. The results of base case and modified criteria scenarios by weighting entropy method

Evaluation matrix in Table 17 was considered in this analysis and criteria weights were calculated by utilizing the entropy method as shown in Table 18. According to the entropy method, the most and least important criteria were fossil fuel share with 34% and service life with 0.70% weight, respectively. When the CO<sub>2</sub> emission reduction target of CDM projects is considered, using additional fossil fuel in the power plant makes sense as an important criterion. In addition to this, O&M, electricity production and capacity follows fossil fuel usage as important indicators with significant weights. Thus, the weights obtained by entropy methods are reasonable to use in the analysis.

After criteria weight determination by entropy method, MAUT was applied to obtain final sustainability scores-ranking and this scenario is called *Base Case Entropy Scenario*. In the literature, some sustainability multi criteria analyses have been performed by considering few criteria divided by capacity or generation value for reliable comparison. In our paper, this idea was considered and sustainability analyses were repeated to make a better comparison. In *Per MW Entropy Scenario*, electricity to grid is divided by capacity and obtained *operating hours*. Moreover, some other criteria were divided by capacity and their new values are obtained as per MW: investment cost per MW (million USD/MW), operation and maintenance cost per MW (million USD/MW/yr), emission reduction per MW (tCO<sub>2</sub>eq/MW), land use per MW (hectares/MW) and job creation per MW (people/MW). In *Per MWh Entropy Scenario*, criteria modifications were done by dividing electricity generation values. Five criteria were divided by generation and new indicators were obtained as follows: investment cost per MWh (million USD/MWh), operation and maintenance cost per MWh (million USD/MWh/yr), emission reduction per MWh (tCO<sub>2</sub>eq/MWh), land use per MWh (hectares/MWh), and job creation per MWh (people/MWh).

Based on scenarios mentioned above, the final sustainability rankings of three scenarios were presented in Fig. 4. It is worth mentioning that Morocco\_160 is the most and Lebanon\_2.2 is the least sustainable project for three scenarios. Morocco\_160 project is 160 MW large-scale grid connected power plant project with a 3-h thermal energy storage without fossil fuel consumption. On the contrary, the project Lebanon\_2.2 has the lowest capacity and emission reduction value

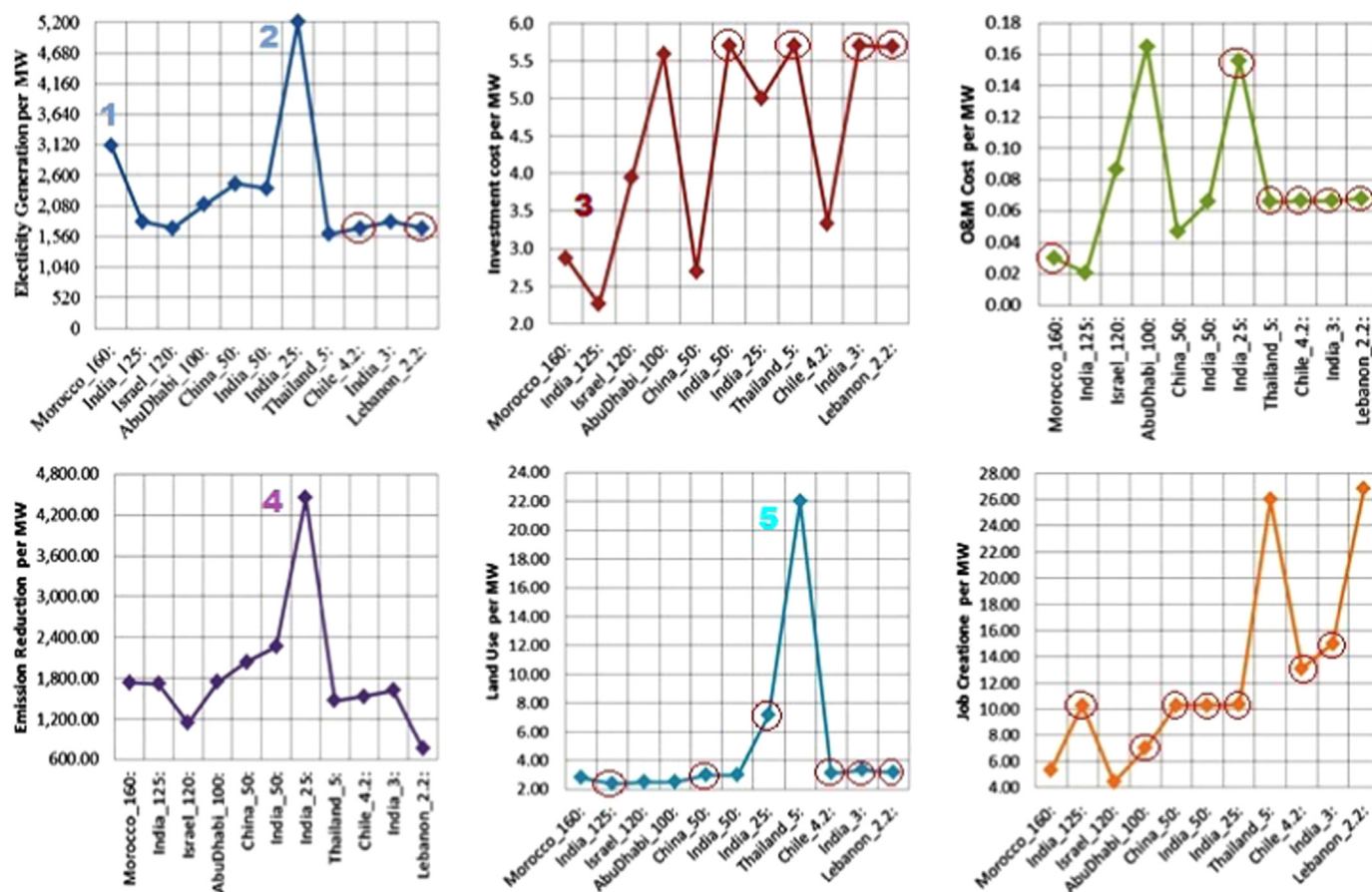


Fig. 3. Solar thermal CDM projects information per MW.

between the alternatives and the fossil fuel consumption is 86%. Another key result is that project Israel\_120 is the third sustainable project for *Per MW<sub>Entropy</sub> Scenario* and *Per MWh<sub>Entropy</sub> Scenario* even though it had lower ranking for *Base Case<sub>Entropy</sub> Scenario*. It is also important to observe that AbuDhabi\_100 which is a utility scale project has lower sustainability rankings for all scenarios when it is compared to larger projects because its additional fossil fuel usage. As a result, as well as each evaluation criterion, considering the units of evaluation indicators such as per MW or MWh is crucial decision and it affects the sustainability rankings.

## 6.2. The results for Equal Weight Scenarios

Criteria weights can be obtained both by using weighting methods and being defined by decision makers. In this section, instead of using a method, criteria weights were defined by direct weighting. It was considered the same value (0.1) for each criterion evenly. For *Equal weight scenarios*, the same analyses in Section 6.1 are repeated for base case (*Base Case<sub>Equal Weight</sub> Scenario*) and modified criteria scenarios (*Per MW<sub>Equal Weight</sub> Scenario*, and *Per MWh<sub>Equal Weight</sub> Scenario*) by considering equal criteria weights. In *Per MW<sub>Equal Weight</sub> Scenario*, electricity, investment cost, O&M, emission reduction, land use, and job creation criteria are divided by capacity and obtained per MW values for these criteria. Moreover, criteria such as: investment cost, O&M,

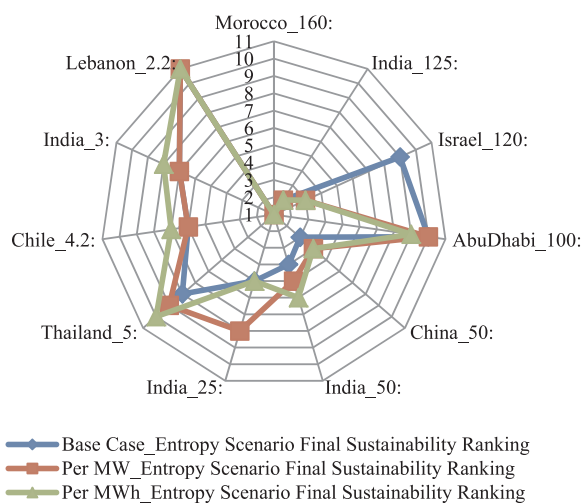


Fig. 4. Final sustainability rankings of selected projects for Entropy Scenarios.

emission reduction, land use, and job creation are divided by electricity generation and obtained per MWh values for *Per MWh<sub>Equal Weight</sub> Scenario*.

As mentioned before, total sustainability rankings were calculated

Table 18

Criteria weights obtained by entropy method.

Evaluation Indicators	Capacity	Electricity	Construction	Investment	O&M	Life	Emission	Land	Fossil	Job
Weight	0.0966	0.1004	0.0223	0.0885	0.1206	0.0070	0.0860	0.0678	0.3400	0.0708

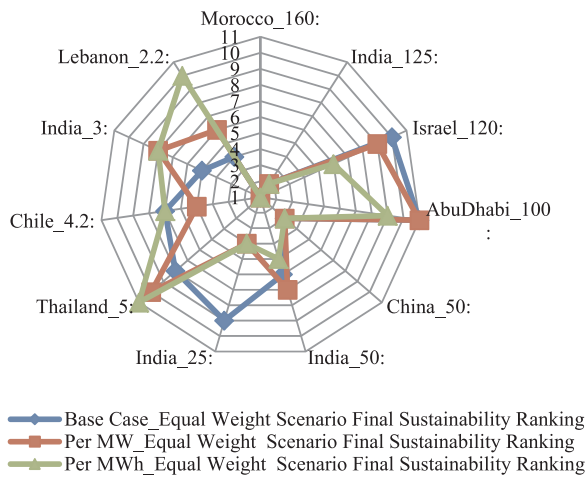


Fig. 5. Final sustainability rankings of selected projects for Equal weight scenarios.

by considering 4 main indicators: technical (capacity, generation, and construction period of the project), economic (investment cost, operation and maintenance cost and service life), environmental (emission reduction, land use, and additional fossil fuel usage), and finally social (the number created employment). The final sustainability rankings of selected projects for all equal weight scenarios are illustrated in Fig. 5. As can be seen, Morocco\_160, India\_125, and China have the first, second and third best rankings for all equal weight scenarios, accordingly. For *Base Case\_Equal Weight* and *Per MW\_Equal Weight Scenarios*, Abudhabi\_100 which has utility scale power project with additional fossil fuel usage is found as the lowest sustainable project. On the contrary, for *Per MWh\_Equal Weight Scenario*, Thailand\_5 has the lowest sustainability ranking between the alternatives. As a conclusion, *Per MW\_Equal weight* and *Per MWh\_Equal weight scenarios* illustrate roughly parallel results even though *Base Case\_Equal weight scenario* shows approximately similar results for only big capacity projects. Thus, the way of factoring in the scale of projects is fundamental in sustainability evaluation.

### 6.3. The results for Environment scenarios

In *Environment scenarios*, instead of using a method, criteria weights were defined by direct weighting. The most important criteria were chosen as environmental indicators with the total weight of 0.40. In addition to this, the weights of social, technical and economic indicators are determined as 0.30, 0.15 and 0.15, accordingly as illustrated in Table 19. It is important to emphasize that determination of weights defined by decision makers can differ from one analysis to other.

Under these assumptions, *Base Case\_Environment Scenario* analysis was developed and modified scenarios were considered. For *Per MW\_Environmental Scenario*, electricity, investment cost, operation and maintenance cost, emission reduction, land use, and job creation are divided by capacity and new values are obtained as per MW. For *Per MWh\_ Environmental Scenario*, criteria modifications are done by dividing electricity generation. Five criteria (investment cost, O&M,

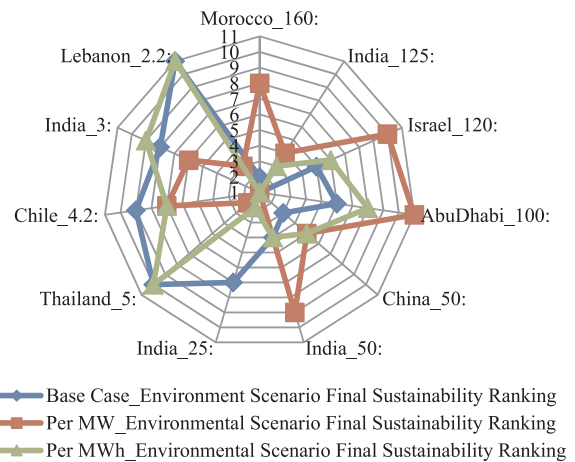


Fig. 6. Final sustainability rankings of selected projects for Environmental scenarios.

emission reduction, land use, and job creation) were divided by generation, new indicators are obtained as per MWh and analysis has done according to new values. Conclusively, final sustainability rankings of three environmental scenarios are illustrated in Fig. 6.

*Base Case\_Environment Scenario* results surprisingly illustrated that India\_125 is the best sustainable projects and Morocco\_160 is the second sustainable project. Moreover, it is expected to see that small-scale projects such as: India\_3, Thailand\_5, Chile\_4.2, and Lebanon\_2.2 have the lowest total sustainability rankings, respectively. On the contrary, for *Per MW\_Environmental Scenario*, it is interesting to see that India\_25, which has 25 MW capacity, 9 h TES and no fossil fuel usage, has the highest while Abudhabi\_100, which has 100 MW capacity and fossil usage, has the lowest sustainability scores. These results are not surprising because the weights of environmental indicators are high and affect the project more if the project has high emission, larger land and additional fossil fuel usage.

Another crucial key finding was that Morocco\_160 had 8th sustainable ranking which is the lowest total sustainability ranking in all scenarios. Moreover, in *Per MWh\_Environmental Scenario*, Morocco\_160 had the highest and Lebanon\_2.2 has the lowest total sustainability rankings as a usual result. Another significant result obtained from Fig. 6 is that *Base Case\_Environment* and *Per MWh\_Environmental Scenarios* illustrated close results although *Per MW\_Environmental Scenario* had less common results. No project is obtained with the same rankings for all three scenarios. Once again, considering the units of evaluation indicators such as per MW or MWh has a significant effect on result and change the sustainability rankings considerably.

## 7. Conclusion

Energy is essential for global development and human life. However, human beings took advantage of different energy sources and used them according to their needs without due consideration for the consequences. Some of the consequences for these activities are irreversible and will impact future generations. This is the case of energy generation from fossil fuel sources and poorly implemented renewable

Table 19  
Environment scenario criteria weights.

<b>Technical Indicators: 0.15</b>	Capacity (MW): 0.05 Electricity to the Grid (MWh/yr): 0.05 Construction period (years): 0.05	<b>Economic Indicators: 0.15</b>	Investment cost (million USD): 0.05 O&M Cost (million USD/yr): 0.05 Service life (years): 0.05
<b>Environmental Indicators: 0.40</b>	Emission reduction (tCO <sub>2</sub> eq): 0.15 Land use (hectares): 0.10 Fossil sources share (%): 0.15	<b>Social Indicators: 0.30</b>	Job creation (people): 0.30

energy projects. Some years ago any renewable energy project was considered sustainable, since when compared to conventional energy projects, their local and global emissions output are much smaller. However, if they are not planned, designed and operated appropriately, they may still have a large negative environmental and social consequence, remaining non-sustainable.

CDM energy projects allow developed countries to implement cost-effective emission-reduction projects in developing countries and also make contribution to sustainable development. The concept of sustainability is fundamental for energy projects and while conceptually well defined; its implementation is still a challenging task. The United Nations' CDM Sustainability Evaluation Tool (SD-TOOL01) evaluates the sustainability of CDM projects by concentrating on three main areas: environmental, social and economic. This tool uses a qualitative evaluation method. It is voluntary for project developers and includes inadequate and general check-list questions. In the SD literature, sustainability assessment generally covered three pillars (environmental, economic, and social). Nevertheless, recently there have been some researchers who are including a fourth and fifth pillars in their sustainability evaluation. While some consider a technical pillar to facilitate technology comparison among projects, others are starting to include risk indicators, to explicitly include uncertainty and potential negative scenarios associated with technology, cost, and environmental damage.

This research includes a comprehensive review of sustainability and multi criteria decision analysis of energy projects. In the first part of review, papers including sustainability assessment and multi criteria analyses in energy subject were classified to propose approaches for CDM projects sustainability assessment. Then, their focus and main contribution to literature were listed. After that, in the second part of the review, studies done for different purposes were categorized based on their indicators. Five main sustainability criteria (technical, economic, social, environmental and risk aspects) were discussed to provide a framework for decision makers to determine the sustainability indicators for CDM projects. Moreover, frequently used multi-criteria decision-methods were classified and summarized to see the method alternatives for authorities who will work on sustainability assessment. Finally, these framework was applied a case study. Project sustainability analysis was performed by using MAUT method for solar thermal

CDM projects under four main indicators: technical, economic, environmental, and social. Also, the analysis was repeated based on several scenarios including different criteria and their weights to understand the impact of criteria selection on results. The results indicated that high capacity projects (160, 125, and 50 MW) without additional fossil fuel usage tend to be more sustainable than smaller projects because of the significant amount of emission reduction in most scenarios. It is also interesting to conclude that projects with solar thermal storage such as India<sub>25</sub> are reached high sustainability when they are considered in environmentally friendly scenarios (*Per MW Environmental Scenario* and *Per MWh Environmental Scenario*).

Even though a project might have the highest ranking for a single criterion, it does not necessarily mean that it would continue to have the highest total sustainability ranking. It must be noted that the selection of indicators and sub-indicators is a crucial step for sustainability evaluation which affects the analysis directly. In order to determine the criteria weights, both objective weighting methods and decision maker's weight preferences can be utilized. Decision makers should consider various scenarios to compare different cases which depend on the country that the project takes place in for instance: environmental conditions, local culture, and renewable energy policy. There is not just one suitable method; thus, the methodology and indicators must be chosen specifically according to the evaluation subject.

Finally, the overall contribution of this paper is proposing a structure to evaluate the sustainability of CDM energy projects. This research can be beneficial to decision makers, researchers and organizations to understand project based evaluation to design and plan better sustainable energy projects. This work can provide further perceptions for the development of sustainable CDM energy projects around the world. Further studies can include sustainability analysis of several energy projects which consist of different methodologies and result comparison.

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## Appendix A

See Table A1

**Table A1**  
Estimation methodology for missing information in Table 17.

Technical	<b>Capacity</b>	Most project present its installed capacity in its PDD, only Chile <sub>4.2</sub> was missing. (a) Chile <sub>4.2</sub> project is constructed to produce 10.5 MW <sub>th</sub> thermal energy. To make a comparison between projects, the thermal capacity of project (MW <sub>th</sub> ) is converted to electricity capacity (MW) by assuming turbine efficiency as 40% [69]. For Chile <sub>4.2</sub> , the capacity is assumed as 4.2 MW.
	<b>Electricity</b>	(b) For the small capacity projects (3–5 MW), it is obtained that annual electricity to the grid is calculated by multiplying capacity with 1600 and 1800 operation hours in their PDD. According to this, it is assumed the average number of operation hours as 1700 and for missing electricity generation values. Thus, the electricity generation values of Chile <sub>4.2</sub> and Lebanon <sub>2.2</sub> are calculated as 7140 MWh/yr and 3740 MWh/yr, respectively
	<b>Construction</b>	(c) Assumption is done according to known construction periods of other projects. Capacity up to 5 MW, construction period is assumed 1 year; for up to 50 MW, it is assumed 2 years; for up to 150 MW, it is assumed 3 years.
Economic	<b>Investment</b>	(d) Investment cost of STPP without storage is assumed 5.7 million USD/MW [70]. Due to this assumption, for India <sub>50</sub> , Thailand <sub>5</sub> , India <sub>3</sub> , and Lebanon <sub>2.2</sub> , the investment cost of the projects are calculated as 285 million USD, 28.5 million USD, 17.1 million USD and 12.5 million USD, accordingly.
	<b>O&amp;M</b>	(e) For STPPs with storage facilities, O&M cost based generation is assumed as 0.03 USD/kWh per year [71]. For Morocco <sub>160</sub> and for India <sub>25</sub> , O&M costs are calculated as 4.8 million USD and 3.9 million USD, accordingly.(f) For STPPs, O&M cost based capacity is assumed as 66USD/kWe per year [71]. For India <sub>50</sub> , Thailand <sub>5</sub> , Chile <sub>4.2</sub> , India <sub>3</sub> , and Lebanon <sub>2.2</sub> , O&M costs are calculated as 3.3 million USD/yr, 0.33 million USD/yr, 0.28 million USD/yr, 0.2 million USD/yr, and 0.15 million USD/yr, respectively.
Environmental	<b>Life</b>	All values are obtained from Project Design Documents.
	<b>Emission</b>	All values are obtained from Project Design Documents.
	<b>Land</b>	

(continued on next page)

Table A1 (continued)

		(g) For Fresnel technology, land use is assumed, 1.88 ha/MWac based on capacity and 1.6 ha/GWh based on generation [72]. For India <sub>125</sub> , land use is calculated as 235 ha based on capacity and 363 ha based on generation. It is assumed 300 ha as an average. (h) India <sub>50</sub> and China <sub>50</sub> have similar capacities; therefore, for China <sub>50</sub> , it is assumed as 150 ha. (i) STPP with nine hours storage requires 1.4 ha/GWh or 7 ha/MW land [72]. With these assumptions, land use for India <sub>25</sub> is calculated 175 ha based on capacity and 182 ha based on generation. It is assumed 180 ha as average. (j) For parabolic technology, land use based on capacity is assumed as 3.8 ha/MWac; based on generation it is assumed as 1.4 ha/GWh [72]. For Chile <sub>4.2</sub> , land use is calculated as 16 ha for capacity based and 10 ha for generation based. Therefore, it is assumed 13 ha as the average. For India <sub>3</sub> , land use is calculated as 11.4 ha for capacity based and 7.6 ha for generation based. Therefore, it is assumed 10 ha as the average. For Lebanon <sub>2.2</sub> , land use is calculated as 8.36 ha for capacity based and 5.24 ha for generation based. Therefore, it is assumed 7 ha as the average.
	<b>Fossil share</b>	(k) In the PDD of Lebanon <sub>2.2</sub> , it is mentioned that in the project, production from solar energy and fossil source will be 2.8 MWh and 17.2 MWh respectively. Therefore, share of fossil fuel consumption is calculated as 86%.
<b>Social</b>	<b>Job</b>	(l) For solar thermal energy projects, it is assumed that 10 temporary and 0.3 permanent jobs created per MW [73,74]. Therefore, For India <sub>125</sub> , totally 1288 jobs are estimated (125 MW*10 = 1250 temporary jobs + 125 MW*0.3 = 38 permanent jobs). For Abu Dhabi <sub>100</sub> which has 68% solar share, totally 700 jobs are estimated (68 MW*10 = 680 jobs temporary + 68*0.3 = 20 permanent jobs). For China <sub>50</sub> and India <sub>50</sub> , totally 515 jobs are estimated (50 MW*10 = 500 temporary jobs + 50*0.3 = 15 permanent jobs). For India <sub>25</sub> , totally 258 jobs are estimated (25 MW*10 = 250 temporary jobs + 25 MW*0.3 = 8 permanent jobs). For Chile <sub>4.2</sub> , totally 55 jobs are estimated (4.2 MW*10 = 42 temporary jobs + 4.2 MW*0.3 = 12.6 permanent jobs.). (m) For India <sub>3</sub> which has, 30 temporary jobs are calculated. In project design document, it is mentioned 15 permanent jobs. Therefore, totally 45 jobs is assumed for India <sub>3</sub> project.

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## Abbreviations

AHP: Analytical Hierarchy Process  
 CERS: Certified Emission Reductions  
 CDM: Clean Development Mechanism  
 CF: Capacity Factor  
 CLFR: Compact Linear Fresnel Reflective  
 COP3: the Third Conference of Parties  
 CRS: Central Receiver System  
 CSP: Concentrated Solar Power  
 ELECTRE: Elimination and Choice Translating Reality  
 FCCC: Framework Convention on Climate Change  
 FF: Fossil Fuel  
 GDP: Gross Domestic Products  
 GHG: Greenhouse Gas  
 HFO: Heavy Fuel Oil  
 HTF: Heat Transfer Fluid  
 KP: Kyoto Protocol  
 LEC: Levelized Electricity Cost  
 LFR: Linear Fresnel Reflector  
 LCOE: Levelized Cost of Electricity  
 MB: Minimum Backup  
 MCDM: Multi Criteria Decision Method  
 MADM: Multi Attribute Decision Making  
 MAUT: Multi Attribute Utility Theory  
 MAVT: Multi-Attribute Value Theory  
 MODM: Multi Objective Decision Making  
 NGCC: Natural Gas Combined Cycle  
 NG: Natural Gas  
 NREL: National Renewable Energy Laboratory  
 O&M: Operation and Maintenance  
 PCF: Prototype Carbon Fund  
 PDD: Project Design Document  
 PP: Power Plant  
 PROMETHEE: Preference Ranking Organization Method for Enrichment Evaluation  
 PV: Photovoltaic  
 RE: Renewable Energy  
 SCA: Solar Collector Assemblies  
 SD: Sustainable Development  
 STE: Solar Thermal Electricity  
 STPP: Solar Thermal Power Plant  
 SWARA: Step-Wise Weight Assessment Ratio Analysis  
 TES: Thermal Energy Storage  
 TOPSIS: Technique for Order Preference by Similarity to Ideal Solutions  
 UAE: United Arab Emirates  
 UK: United Kingdom  
 UN: United Nations  
 UNFCCC: United Nations Framework Convention on Climate Change  
 USA: United States of America  
 UTA: Utility Theory Additive  
 WSM: Weighted Sum Method  
 WPM: Weighted Product Method